AGU PUBLICATIONS

Earth's Future

COMMENTARY

10.1002/2016EF000356

White Arctic vs. Blue Arctic: A case study of diverging stakeholder responses to environmental change

Robert Newton[1], Stephanie Pfirman[1,2], Peter Schlosser[1,3], Bruno Tremblay[1,4], Maribeth Murray[5], and Rafe Pomerance[6]

[1]Geochemistry, Lamont Doherty Earth Observatory, Palisades, New York, USA, [2]Environmental Science, Barnard College, New York, New York, USA, [3]Department of Earth and Environmental Engineering and The Earth Institute/Columbia, Columbia University, New York, New York, USA, [4]Department of Atmospheric and Oceanic Sciences, McGill University, Montréal, Quebec, Canada, [5]Arctic Institute of North America and the Department of Anthropology and Archeology, Arctic Institute of North America, University of Calgary, Calgary, Alberta, Canada, [6]Polar Research Board, Washington, District of Columbia, USA

Key Points:

- The Arctic is likely to experience ice-free summers for decades before warming can be reversed through mitigation or engineering solutions
- Diverse, often conflicting interests will emerge as ecological conditions, economies, and societies adapt to the new climate
- Development of options for adaptation or a return to perennial sea ice must account for these stakeholder conflicts

Corresponding author:
R. Newton, bnewton@ldeo.columbia.edu

Citation:
Newton, R., S. Pfirman, P. Schlosser, B. Tremblay, M. Murray, and R. Pomerance (2016), White Arctic vs. Blue Arctic: A case study of diverging stakeholder responses to environmental change, *Earth's Future*, *4*, 396–405, doi:10.1002/2016EF000356.

Received 2 FEB 2016
Accepted 5 JUL 2016
Accepted article online 8 JUL 2016
Published online 3 AUG 2016

Abstract Recent trends and climate models suggest that the Arctic summer sea ice cover is likely to be lost before climate interventions can stabilize it. There are environmental, socioeconomic, and sociocultural arguments for, but also against, restoring and sustaining current conditions. Even if global warming can be reversed, some people will experience ice-free summers before perennial sea ice begins to return. We ask: How will future generations feel about bringing sea ice back where they have not experienced it before? How will conflicted interests in ice-covered vs. ice-free conditions be resolved? What role will science play in these debates?

1. Introduction

Twenty-four years after the Framework Convention on Climate Change sought to avoid "dangerous" climate change [*United Nations*, 1992], CO_2 concentrations at the Mauna Loa observatory have crossed a significant threshold: >400 ppm CO_2 year round [*Betts et al.*, 2016]. While it is difficult to specify a boundary between "safe" and "dangerous" warming, the debate is currently centered between 1.5° and 2° above 1990 levels [e.g., *Hansen et al.*, 2013a]. To stabilize at a given global mean temperature, the allowable CO_2 concentration depends on "climate sensitivity," the response of the climate system to greenhouse gas forcing. Sensitivity estimates from models and paleoclimate data vary by a factor of about two, but a central estimate is about 2°C warming per 1000 GtC (gigatons of carbon) cumulative emissions [*Allen et al.*, 2009; *Meinshausen et al.*, 2009; *Matthews et al.*, 2012; *Hansen et al.*, 2013a, 2013b]. Thus, the target set in Paris in 2015 [*United Nations*, 2016] of no more than 2°C increase above preindustrial mean temperature implies holding cumulative CO_2 emissions below about 1000 GtC. Emissions since industrialization have already been over 500 GtC and are currently about 10 GtC/year [*Le Quere et al.*, 2015]. The only IPCC concentration pathway that holds temperatures within the Paris limit is the Representative Concentration Pathway 2.6 (RCP2.6) [*van Vuuren et al.*, 2011], in which net emissions peak in the next few years and are zero, or even slightly negative, by about 2050. Similarly, *Hansen et al.* [2013a] estimate that to hold the climate within the range experienced since the last deglaciation will require at least a 6% annual reduction in carbon emissions. Achieving such a trajectory is daunting from social, technical, and economic perspectives as it requires a massive and rapid decarbonization of the economy coupled with very aggressive reforestation or artificial means of sequestering carbon from the atmosphere.

Beyond the technical issues, the challenge of controlling, managing, or possibly reversing the impacts of human activities on our planet has an increasingly visible other dimension to which we believe too little attention has been paid: the conflicting interests of different stakeholder communities. In many instances, this arises as a conflict between industries, political segments, or even nations that have an interest in continuing business as usual, deferring any environmental costs to the future, versus those that desire immediate action to mitigate or remediate environmental problems in order to maintain existing conditions or return to a state perceived as healthier or more in balance with nature. There are communities of interest among stakeholders who see opportunities in new uses of planetary resources in a future world

10.1002/2016EF000356

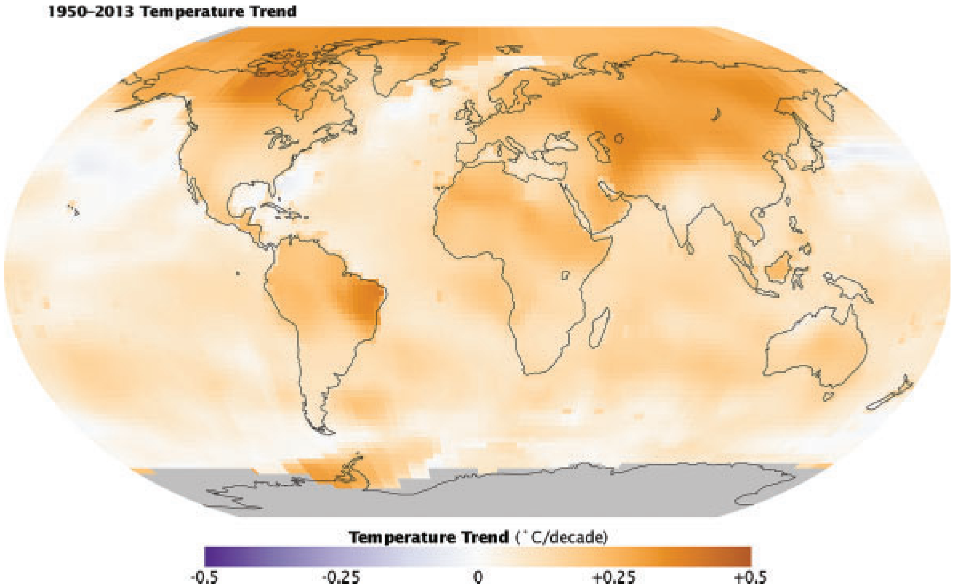

Figure 1. The temperature tendency, 1950–2013, in degrees Celsius per decade (NASA Earth Observatory: http://earthobservatory.nasa.gov/IOTD/view.php?id=82918&eocn=home&eoci=iotd_title).

shaped by continued and unabated human activity. We are thus entering into a phase of discussions about how to respond to the impacts of anthropogenically induced environmental change that is characterized by a growing tension between stakeholders who would like to minimize or reverse the impact of human activities and those who would like to exploit them and thus are not interested in remediation.

In the Arctic, which has historically been too cold for many types of industrial activity, and where temperature is rising more than twice as fast as the planetary average (Figure 1), these dynamics are playing out more rapidly, and in some ways more dramatically, than at lower latitudes. Warming is already reducing sea ice (Figure 2), driving glacial retreat [*Stroeve et al*., 2012; *Tedesco et al.*, 2015], and expanding growing seasons [*Zheng et al.*, 2011] as the Arctic moves towards a new annual cycle that includes a largely ice-free (less than 1 million square km) ocean in the summer [*Overpeck et al.*, 2005; *Mahlstein and Knutti*, 2012].

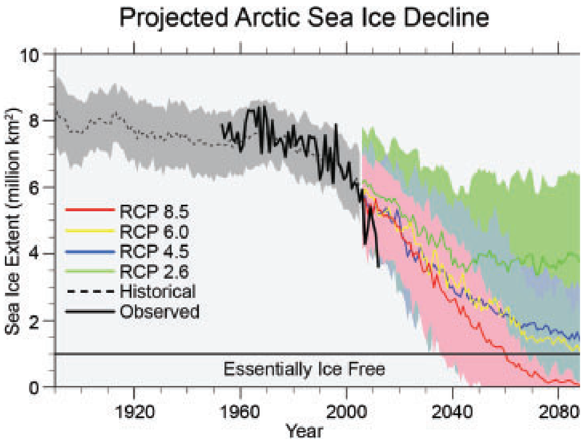

Figure 2. Observed and simulated Arctic sea ice minimum. Black: observations. Colors: IPCC models with radiative forcing from the Representative Concentration Pathways. Green: RCP2.6, Blue: 4.5, Yellow: 6.0, Red: 8.5. Solid lines are ensemble averages. (Adapted from *Stroeve et al.*, 2012. Accessed at: http://nca2014.globalchange.gov/report/our-changing-climate/melting-ice).

Some interest groups are actively planning for an opening of the Arctic Ocean, including a number who are already investing in new infrastructure to take advantage of emerging economic opportunities. For example, at the newly formed Arctic Circle, which convenes businesses and organizations from around the world to "strengthen the international focus on the future of the Arctic," climate change is a central focus.

Emergence of an ice-free Arctic summer raises issues that we have never had to deal with before, including what, if anything, *can* be done to preserve a "white" Arctic and whether, in fact, anything *should be done*? Below, we use the implications of the loss of Arctic sea ice as an example for how to frame emerging tensions and to explore which options exist to navigate the increasingly complex task of responding to Arctic environmental change.

10.1002/2016EF000356

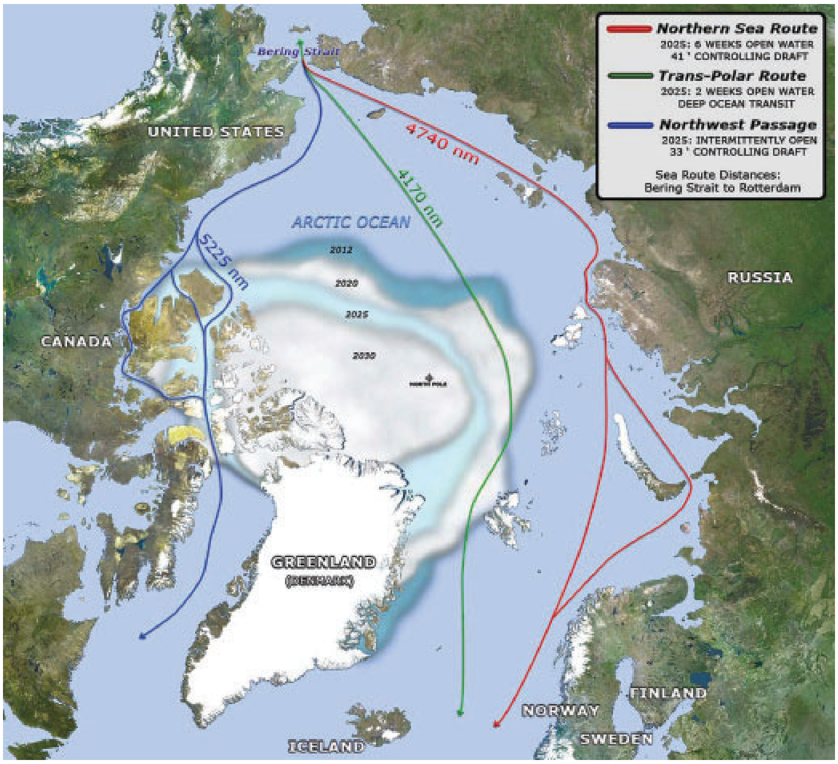

Figure 3. Anticipated future Arctic transit routes superimposed over Navy consensus assessment of sea ice extent minima in 2012, 2020, 2025, and 2030. Graphics courtesy of the U.S. Navy (http://www.doncio.navy.mil/CHIPS/ArticleDetails.aspx?ID=5256).

Table 1. A Partial List of the Services Provided by Arctic Sea Ice With (Left) and Outside (Right) the Arctic Region.

Within-Arctic Sea Ice Services	Global Arctic Sea Ice Services
Wildlife habitat	Planetary albedo
Subsistence hunting and fishing	Ocean circulation
Coastal infrastructure support	Carbon storage
Intra-Arctic security	Atmosphere and weather
	Sea level
	International security

2. Rationale for Sustaining a White Arctic

For at least the last 6000 years, the central Arctic Ocean has been covered by a perennial ice pack so that its liquid surface was only exposed to the atmosphere through leads and polynyas (small, often intermittent, openings in the sea ice) [*Walsh and Chapman*, 2014]. The seasonally ice-free zone (the area ice-free in summer but ice-covered in winter) was located, as long as humans have been there to observe it, almost entirely over the broad continental shelves that ring the Arctic Ocean (Figure 3). Losing the central Arctic sea ice in summer means dramatic changes both in the Arctic and beyond [e.g., *Frances and Vavrus*, 2012; *Lantuit et al.*, 2012; *Struzik*, 2012; *Cohen et al.*, 2014]. It means altering, or even losing altogether, an existing set of ecosystem and climate system services based on the historical Arctic conditions. These services have been widely described elsewhere [e.g., *Mauritzen and Haakkinen*, 1997; *Koenigk et al.*, 2007; *Eicken et al.*, 2009; *Tarnocai et al.*, 2009; *Hugelius et al.*, 2014; *Schuur et al.*, 2015] and include the loss of habitat and food supply [e.g., *MacCracken*, 2012; *Stirling and Derocher*, 2012], large impacts on infrastructure, increased security concerns, increased global warming, and possibly an increase in certain types of extreme weather patterns in mid latitude (Table 1).

3. Interests in a Blue Arctic

As existing functions are lost, new ones will arise. Without the light-limiting sea ice cover, biological production will increase over the central Arctic Ocean [*Frey et al.*, 2015]. Fish species normally limited to the northern parts of the Atlantic and Pacific oceans will likely extend their ranges north into the Arctic [*Kovacs et al.*, 2011; *Laidre et al.*, 2015]. Terrestrial biomes will migrate north and replace Arctic ones [*Post et al.*, 2009], and commercial activity in the Arctic is widely expected to increase. Above the Arctic Circle, there will still be up to 6 months of darkness, and therefore, winter conditions will continue to be cold, with extensive sea ice cover throughout most of this century. Nonetheless, expanded fishing, oil, and natural gas exploration and production; mining; shipping (Figure 3) [*Arctic Council*, 2009; *Pelletier and Lasserre*, 2012; *Pizzolato et al.*, 2013; *Smith and Stephenson*, 2015], and touristic activity [*Lemelin et al.*, 2012] will increase the demand for labor. It remains to be seen what labor patterns emerge, whether previously stable or even declining towns will see renewed growth, or if the seasonal migration of workers will be dominant [*Heleniak*, 2013; *Rasmussen*, 2013a, 2013b; *Vaguet*, 2013; *Zalkind*, 2013; *Heleniak and Bogoyavlensky*, 2014]. Municipal, transportation, and commercial infrastructure will be required to support these new developments. Between public infrastructure and privately held plants, rigs, platforms, mines, and ships, it is easy to imagine that over several decades, hundreds of billions of dollars might be invested to support trillions of dollars' of resource extraction and other commercial activity [e.g., *Klett*, 2011; *Houseknecht et al.*, 2012a, 2012b]. Of the Arctic lands, 80% lie within northern Canada and Russia, and both nations have previously expressed strong interest in the development of nonrenewable resources, tourism, and civil infrastructure [see, e.g., the Russian Federation Policy for the Arctic to 2020—http://www.arctis-search.com/Russian+Federation+Policy+for+the+Arctic+to+2020, and *Zysk*, 2014]. In the United States, there has been a long and often acrimonious debate about whether to aggressively pursue offshore drilling in the Arctic and whether to facilitate oil sands petroleum transportation to U.S. ports. With the recent change in Canada's national government and the ascendency of the United States to the chairmanship of the Arctic Council, the Obama and Trudeau administrations are collaborating on sustainable approaches to Arctic development, which include substantial targets for protected terrestrial and marine areas (e.g., http://pm.gc.ca/eng/news/2016/03/10/us-canada-joint-statement-climate-energy-and-arctic-leadership). One has to note, nonetheless, that these statements are in the context of pressure from within both governments to increase northern development, including offshore petroleum extraction, and are potentially at odds with Russian goals for the region. Increased international interest in membership in the Arctic Council among non-Arctic nations, such as China and Singapore, and the establishment of the new Arctic Circle are further testament to the increased interest in the opportunities offered by a changing Arctic.

4. Possibilities for Restoring and Sustaining a White Arctic

If we wanted to restore and sustain a white Arctic, could we? If we cool the region, the answer is almost certainly yes [*Amstrup et al.*, 2010; *Mahlstein and Knutti*, 2012]. Model studies indicate that there is little lag and virtually no hysteresis in the Arctic sea ice response to surface air temperatures [*Armour et al.*, 2011; *Tietsche et al.*, 2011]. If the Arctic were to be cooled, the sea ice would in all likelihood return; i.e., there is probably no "point of no return" [*Ridley et al.*, 2012].

Intra-Arctic technological strategies to preserve Arctic sea ice have been proposed, e.g., covering sea ice with a reflective material, as some ski resorts have done recently with their glaciers, or spraying sea water into the atmosphere to increase snow and ice formation. However, to date, none has earned wide support as a physically effective and economically viable solution on the geographic scale of the Arctic Ocean. The extent and mobility of sea ice renders surface solutions such as these impractical.

Were an economically feasible local—Arctic-specific—cooling technology to be developed, the dynamics of atmosphere and ocean circulation would seriously steepen the challenge of maintaining Arctic sea ice as temperatures continued to rise at lower latitudes. Research with climate simulations and observationally based historical analysis products indicates that atmospheric and oceanic circulation links the Arctic and lower latitudes tightly in a single climate system. As shown by *Tilmes et al.* [2014], cooling the Arctic would accelerate the northward transport of heat in response to the increased north–south temperature gradient.

There does not appear to be any way to control the surface air temperature over the Arctic Ocean without changing conditions over the more heavily populated regions of the northern hemisphere.

Rather, in order to regrow a stable summer sea ice cover, the current warming trend would have to be reversed, and that is unimaginable without large changes on a global scale. Aggressive measures would be required to reduce the greenhouse gases, especially carbon dioxide, in the atmosphere (carbon dioxide reduction—CDR) [*National Research Council*, 2015] through a combination of emissions reductions—decarbonization of the economy—and carbon capture and sequestration. In addition, some have proposed climate interventions targeting Arctic cooling through reducing, regionally or globally, the solar energy reaching the earth's surface (solar radiation management—SRM) [*Crutzen*, 2006; *Caldeira and Wood*, 2008; *National Research Council*, 2015].

Cooling the Arctic through SRM remains very controversial. The distributions of light, temperature, and precipitation will be different, even if the global mean temperature is about the same, and the ecological consequences of the differences are not predictable [*Ricke et al.*, 2010]. Modeling studies indicate that the combination of CDR + SRM could potentially have severe impacts on a local level [*Robock et al.*, 2008]. In addition, there is currently no institutional basis for deciding when, where, or how much SRM should be undertaken. One could imagine a scenario in which nations with large agricultural sectors or coastal cities wish to move forward aggressively with SRM to maintain current crop conditions or combat sea level rise, while high-latitude nations or those dependent on monsoons, which may be sensitive to solar radiation distributions, protest. Conflated with the relatively low cost of SRM, one could easily imagine conflicts between climate winners and losers or competing SRM implementations. It is completely unclear in what court such a dispute would be adjudicated. In the absence of an effective governance structure, SRM would put a great deal of power in the hands of the implementing institution(s). Cessation on short time scales would lead to extremely rapid rebound toward high temperatures [*Jones et al.*, 2013]. There would be rapid loss of sea ice and broad temperature and precipitation changes on time scales shorter than many plant and animal generations.

Proponents counter that (1) humans are already engineering the climate system and (2) the urgency of the situation justifies taking drastic corrective action. For many "geoengineers," SRM is a necessary stop-gap measure to minimize environmental damage while we move toward CDR. The debate over whether to implement SRM and, more broadly, how much to invest in climate stabilization, over what time frame, and what price to put on carbon pollution is already playing out in academic, political, and economic forums. The fate of Arctic sea ice hangs on those global policy debates, in which the Arctic, where about 4 million people live, has a relatively small voice.

5. Regional and Inter-Regional Policy Conflicts

In a sense, we are becoming aware of the globally linked nature of the Arctic climate at the same time that the Arctic is being drawn ever more tightly into global economic and political systems. Neither the Arctic nor lower-latitude populations are monolithic in their approach to a warmer planet. Each region is composed of diverse constituencies with conflicting points of view, and even the basis for each group's legitimacy is different. Canada will be an interesting example to watch. The previous government's Arctic policy was very pro-development (e.g., Canada's Northern Strategy—http://www.northernstrategy.gc.ca/index-eng.asp), but the new government has promised a different direction. For example, Canada has granted significant sovereignty to Inuit people though the settlement of the Inuvialuit Land Claim in the western Canadian Arctic (1984, http://www.irc.inuvialuit.com/about/finalagreement.html) and the creation of the Inuit territory of Nunavut in the east (1999). Yet the previous Conservative-led Federal government in Ottawa had clearly stated its intention to pursue ambitious natural resource extraction projects there, perhaps in part because the Territory remains fiscally dependent, receiving upwards of 92% of revenue from Ottawa [*Holmes*, 2013], Critically, the federal government of Canada retains control over all offshore minerals, natural gas, and energy, which are not addressed in the Nunavut Final Agreement [*Colton et al.*, 2015; *Kerr et al.*, 2015]. The new Liberal-led Federal government has promised a nation-to-nation relationship with the Inuits. How that will impact policy around offshore development is uncertain, but one has to note that about 84% of oil and gas reserves are oceanic [*Bird et al.*, 2008]. The Russian Federation's plan for the Arctic states straightforwardly that development of its Arctic territories will be aggressive and will serve broad national economic interests. Russia, Canada, and the United States are all increasing their military investments in the Arctic [*Government Accounting Office*, 2015], where tensions are already increasing, both as a result of resource competition [*Murray*, 2012] and as spillover from global conflict [*Kapyla and Mikkola*, 2013, 2015].

Some Arctic populations see warming, sea ice loss, and habitat changes as severe threats to their traditional ways of living. Discussions around the founding of a University in Nunavut, for example, focus on building traditional knowledge in language, art, culture and health. Representatives of the Gwich'in people have traveled thousands of miles to meet with Indigenous peoples from Latin America to form alliances to oppose oil drilling. On the other hand, other groups and individuals in Indigenous communities are closely focused on opportunities for reaping royalties from resource leases. For many Arctic people, fisheries, oil, gas, and mineral royalties, along with tourism revenues and participation in logistical and shipping industries, could potentially represent a viable path away from poverty, colonial dependence, and poor health outcomes. *Nuttall* [2013], writing about the Greenland parliament's decision to permit uranium mining, notes that development plans have resulted in political and social debates encompassing both the development issues per se, including environmental and cultural protections, and the process by which decisions about development will be made in the future. In the face of the ongoing rapid expansion of extractive industries, *Hansen et al.* [2016] refer to both "high hopes for the future and anxieties among the local population," stating that a social impact assessment is needed in Greenland.

Meanwhile, governments of tropical island nations and low-lying coastal nations see global warming as an existential threat. Some highly developed nations are beginning to regulate carbon and move toward carbon-neutral energy production. Others, notably the United States, are unable to come to any meaningful consensus about the existence of a threat from climate change. While the United Nations and the Arctic Council provide forums in which these issues can be discussed, there are, at present, no venues above the national level in which such conflicts can be adjudicated, let alone resolved. Within the Arctic, the two most viable forums are the Arctic Council and the UNCLOS mechanisms, but the first operates in an advisory capacity, the second lacks a viable enforcement mechanism, and the largest Arctic economy, the United States, is not a signatory.

The absence of an international governance mechanism leaves critical questions unanswered: Is it possible to treat Arctic sea ice as part of a global commons, providing critical climate services to the global community? If so, what governance structure would be required? How would the research community and the relevant governmental bodies interact to ensure that this very complex and incompletely understood system is managed to the best likely outcomes? If the Arctic climate is not treated as a commons, then who gets to decide whether anything should be done about sea ice loss? Where would dissenting nations or stakeholders turn to lodge their disagreements? Will the global community of nations allow a single nation, or small group of nations, to take climate action on its own? If not, how will "optimal" goals be established? Is it feasible to enforce international consensus regarding climate strategies? What latitude do nongovernmental actors, such as large corporations or industry-wide associations, have to act on their own? In the absence of legal restrictions on climate action, would practical economic constraints lead to self-regulation? How will the impacts of actions (or inaction) of Arctic nations on extra-Arctic people be taken into account? And vice versa: what recourse will Arctic nations or peoples have if the actions or inaction of lower-latitude communities continue to cause radical changes in Arctic conditions? An ice-free Arctic will occupy a strategic position as a Mediterranean sea linking Europe, North America, and Asia. What commercial and military competitions will arise, and what structures will be required to manage them?

6. Trajectory: White Arctic—Blue Arctic—White Arctic?

Given the scope of changes required to stabilize global climate and the size of investment that would be stranded in high-carbon infrastructure, we do not believe that greenhouse warming can be reversed in time to prevent the loss of most of the summer sea ice cover in the Arctic. On the other hand, we do believe that the high cost of climate change [e.g., *Ackerman and Stanton*, 2008; *Channell et al.*, 2015] ensures that measures to reduce atmospheric temperatures will eventually be taken. Temperatures would come back down, and the perennial sea ice cover would return. If we are correct, there will be a period during which summer sea ice would diminish followed by a largely sea ice-free Arctic Ocean during summer for perhaps several decades or longer, followed by a subsequent regrowth of summer sea ice on time scales of decades to

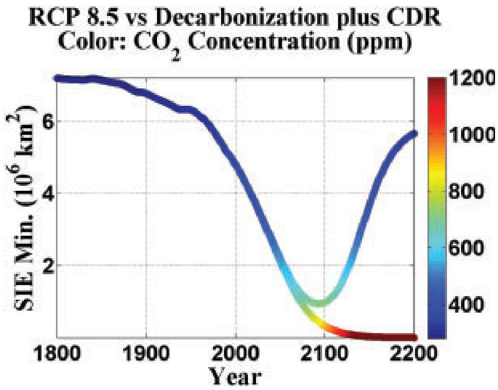

Figure 4. Projections of minimum sea ice extent (SIE) under a business as usual pathway (RCP8.5) and a modified scenario that assumes aggressive decarbonization and CDR to reduce CO_2 from a peak of about 600 ppm in 2100 toward 20th century levels. CMIP-5 ensemble means were used to estimate the summer SIE minimum sensitivity to greenhouse gas warming.

centuries, depending on how CDR is implemented. Figure 4 demonstrates two potential futures. One pathway follows IPCC RCP 8.5 [*Riahi et al.*, 2011] in the 21st century and then continues unabated, with CO_2 concentrations rising to about triple their current value. Summer sea ice essentially disappears in the 21st century and never comes back. A second scenario follows RCP 8.5 until about 2050 but then assumes aggressive decarbonization, reforestation, and carbon dioxide capture, with CO_2 concentrations returning below 400 ppm in the 22nd century. For both scenarios, the observed relationship between atmospheric CO_2 concentrations and minimum sea ice extent is projected into the future using an average of the relationships in the CMIP RCP8.5 projections.

Little attention has been paid to the likely diversity of responses to the purposeful reversal of global warming (Table 2). How will nations and industries in and outside the Arctic that profit from sea ice-free conditions react to the regrowth of Arctic summer sea ice? Will the genetic and ecological capital required to rebuild current biomes still be available? Is it possible to establish the right to reverse Arctic development before it takes place? For example, it has been suggested that a sea ice reserve be created that would limit development within a region where ice would be restored. Is it reasonable to believe that future generations, having adapted to a warmer Arctic, will want to return it to the current state?

As with global-scale SRM, there exists no institutional framework within which to address such issues. Nor is there consensus about the value of the current Arctic climate among the stakeholders in Arctic climate change, including the national governments who exercise sovereign rights over all but the central part of the Arctic Ocean. We are unaware of a precedent for an entire region being driven to fundamentally new conditions by human action while society debates how a future generation will engineer the transition back. Interestingly, we confront an environment that is changing in ways that are relatively predictable. We have the capability to predict what a future return to a "white" Arctic would look like based on a combination of historical observations and climate models. Does it make sense to issue a "fair warning" to commercial organizations that development within the historical ice pack should be regarded as temporary? Could the Arctic nations, for example, draw a line around the late 20th century perennial ice pack and preemptively limit long-term development there?

7. Moving Forward

The Arctic system will adjust to human activities whether those activities are ad hoc or planned, informed by scientific understanding of the system or not. If no coordinated, collaborative solutions emerge, then the way forward will be established by "facts on the ground" that emerge from existing power relations and ad hoc, short-term coalitions. Those organizations with the greatest capacity for rapid, large-scale mobilization

Table 2. Competing Interests in Having an Ice-Covered (White) or an Ice-Free (Blue) Summer Arctic Ocean

White Arctic	Blue Arctic
Arctic residents	Arctic residents
Tourism	Tourism
Fishing	Fishing
Environmental groups	Oil, gas, minerals
Global coastal communities/cities — sea level rise	Shipping
Global society — temperature maintenance	Inertia — existing infrastructure
Northern hemisphere residents — weather?	

(operational government agencies, industrial corporations, investment banks) will dominate the decision space. Organizations with long time scales between learning and accomplishment (grassroot NGOs, multilateral diplomatic organizations, elected legislatures, scientific organizations) will find themselves perennially running from behind, frustrated by the gap between the clarity of their vision and the small impact they have on de facto policy, and local communities will have to deal with changes as they occur around them.

Science has a critical role to play as human communities navigate these contentious issues, and many scientists now interact directly with policy analysts, NGOs, government officials, and other stakeholders, both in delivering their results and in setting their research agendas. Others in the scientific community would rather see a greater separation between their own research activities and "politics." However, in many aspects of climate science, the link between fundamental research and policy has become immediate. Significant new findings change the ways that stakeholders perceive their interests and how they perceive the impact of policies on their near and long-term futures. For better or worse, we are now part of the political process, and it is not useful to act as though the information we deliver is not going to have partisan impacts and provoke partisan responses.

Finding a policy pathway through the upcoming climatic shifts will require the engagement of working collaboratives of scientists, policy analysts, governing bodies, the private sector, Indigenous organizations, and NGOs. Negotiating solutions involve international strategic considerations — meaning that along with local communities and state decision makers, national governments will have to play central roles. Participation of natural and social scientists in these negotiations is imperative.

Lower-latitude nations will also see transitions, both forward to a warmer world and then — we predict — in returning to a cooler one. Similar issues will arise regarding the interests of communities and industries that will have adapted to a greenhouse gas world. The current transitions are accidental byproducts of economic activity, whereas the transition back will be deliberate. Intra- and international conflict will arise in both directions, and the Arctic will likely be at the leading edge of change both times. This may make it a good laboratory for the emergence of forms of organization and governance to respond to the first transition and manage the second. At the same time, Arctic institutions are likely not to dominate the solutions, not even as they regard sea ice retention. Rather, the Arctic will be but one player in the global geopolitical system to which it is becoming increasingly bound.

Acknowledgements
The authors gratefully acknowledge the Clean Air Task Force and contributions of the participants in the 2013 White Arctic/Blue Arctic Workshop at Columbia University. The Columbia Climate Center hosted the workshop. Special thanks to Theresa Hernandez, who was in charge of the logistical arrangements of the workshop. Support for the workshop was provided by the Flora Family Foundation, the Heising-Simons Foundation, the Lamont-Doherty Earth Observatory Climate Center, the PoLAR Climate Change Education Partnership through Grant Number DUE-1239783, and the National Oceanic and Atmospheric Administration. The contributions of Bruno Tremblay, Robert Newton and Stephanie Pfirman were partially supported by the Office of Naval Research grant ONR - N00014-11-1-0977. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or other funding agencies.

References

Ackerman, F., and E. A. Stanton (2008), *The Cost of Climate Change*, Natl. Resour. Defense Counc., New York City, N. Y.

Allen, R.A., D. J. Frame, C. Huntingford, C. D. Jones, J. A. Lowe, M. Meinshausen and N. Meinshausen (2009). Warming caused by cumulative carbon emissions towards the trillionth ton. *Nature*, *458*, 1163–1166, doi: 10.1038/nature08019.

Amstrup, S. C., E. T. DeWeaver, D. C. Douglas, B. G. Marcot, G. M. Durner, C. M. Bitz, and D. A. Bailey (2010), Greenhouse gas mitigation can reduce sea-ice loss and increase polar bear persistence, *Nature*, *468*, 955–958, doi:10.1038/nature09653.

Arctic Council, 2009. Arctic Marine Shipping Assessment 2009 Report. Arctic Counc., Norwegian Chairmanship, Oslo, Norway. PDF. [Available at: http://www.arctic.noaa.gov/detect/documents/AMSA_2009_Report_2nd_print.pdf.]

Armour, K. C., I. Eisenman, E. B. Blanchard-Wrigglesworth, K. E. McCusker, and C. M. Bitz (2011), The reversibility of sea ice loss in a state-of-the-art climate model, *Geophys. Res. Lett.*, *38*(L16705), 1–5, doi:10.1029/2011GL048739.

Betts, R. A., C. D. Jones, J. R. Knight, R. F. Keeling, and J. J. Kennnedy (2016), El Nino and a record CO_2 rise, *Nat. Clim. Change*, doi:10.1038/nclimate3063.

Bird, K. J., R. R. Charpentier, D. L. Gautier, D. W. Houseknecht, T. R. Klett, J. K. Pitman, T. E. Moore, C. J. Schenk, M. E. Tennyson and C. J. Wandrey (2008), Circum-Arctic resource appraisal; estimates of undiscovered oil and gas north of the Arctic Circle, *U.S. Geological Survey Fact Sheet 2008–3049*, 4 p. [Available at http://pubs.usgs.gov/fs/2008/3049/.]

Caldeira, K., and L. Wood (2008), Global and Arctic climate engineering: numerical model studies, *Philos. Trans. R. Soc. A*, *366*(1882), 4039–4056, doi:10.1098/rsta.2008.0132.

Channell, J., E. Curmi, P. Nguyen, E. Prior, A. R. Syme, H. R. Jansen, E. Rahbari, E. L. Morse, S. M. Kleinman, and T. Kruger (2015), *Energy Darwinism II: Why a Low Carbon Future Doesn't Have to Cost the Earth*, Citi Global Perspect. Solutions, New York City, N. Y.

Cohen, J., et al. (2014), Recent Arctic amplification and extreme mid-latitude weather, *Nat. Geosci.*, *7*, 627–637, doi:10.1038/ngeo2234.

Crutzen, P. J. (2006), Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma? *Clim. Change*, *77*(3–4), 211–220, doi:10.1007/s10584-006-9101-y.

Eicken, H., A. L. Lovecraft, and M. L. Druckenmiller (2009), Sea-ice system services: a framework to help identify and meet information needs relevant for Arctic observing networks, *Arctic*, *62*(2), 119–136, doi:10.14430/arctic126.

Frances, J. A., and S. J. Vavrus (2012), Evidence linking Arctic amplification to extreme weather in mid-latitudes, *Geophys. Res. Lett.*, *39*, L06801, doi:10.1029/2012GL051000.

Frey, K.E., Comiso, J.C., Cooper, L.W., Gradinger, R.R., Grebmeier, J.M., Saitoh, S.-I. and Tremblay, J.-E. (2015), Arctic ocean primary productivity, in *Arctic Report Card: Update for 2015*. [Available at http://www.arctic.noaa.gov/reportcard/ocean_primary_productivity.html.]

Government Accounting Office (2009), *Alaska Native Villages: Limited Progress Has Been Made on Relocating Villabes Threatened by Flooding and Erosion*, Gov. Account. Off., Washington, D. C. [Available at http://www.gao.gov/assets/300/290468.pdf.]

Government Accounting Office (2015), *Arctic Planning: DOD Expects to Play a Supporting Role to Other Federal Agencies and Has Efforts Under Way to Address Capability Needs and Update Plans*, Gov. Account. Off., Washington, D. C. [Available at http://www.gao.gov/assets/680/670903.pdf.]

Hansen, J., et al. (2013a), Assessing "Dangerous Climate Change": required reduction of carbon emissions to protect young people, future generations and nature, *PLoS One*, *8*(12), e81648, doi:10.1371/journal.pone.0081648.

Hansen, J., M. Sato, G. Russell, and P. Kharecha (2013b), Climate sensitivity, sea level and atmospheric carbon dioxide, *Philos. Trans. R. Soc. A*, *371*, 20120294, doi:10.1098/rsta.2012.0294.

Hansen, A. M., F. Vanclay, P. Croal, and A.-S. H. Skjervedal (2016), Managing the social impacts of the rapidly-expanding extractive industries in Greenland, *Extract. Ind. Soc.*, *3*(1), 25–33, doi:10.1016/j.exis.2015.11.013.

Heleniak, T. (2013), *Boom and Bust: Population Change in Russia's Arctic Cities. Policy Note presented at the Arctic Urban Sustainability Conference, May 30–31, 2013*, George Wash. Univ., Washington, D. C. [Available at http://www.gwu.edu/˜ieresgwu/assets/docs/Heleniak_BoomandBust%20PopulationChange.pdf.]

Heleniak, T., and D. Bogoyavlensky (2014), Arctic populations and migration, *Arctic Human Development Report: Regional Processes and Global Linkages*, Larsen, J.N. and Fondahl, G., Nordic Council of Ministers, Copenhagen. ISBN 978-92-893-3883-7. 10.6027/TN2014-567. 53 – 106.

Holmes, L. (2013), Nuna-Regionalism: A Vision of Iqaluit Regionalism. (Doctoral dissertation). Retrieved from the UWSpace, the University of Waterloo's institutional repository. [Available at https://uwspace.uwaterloo.ca/handle/10012/7354].

Houseknecht, D.W., K.J. Bird, and C.P. Garrity (2012a), Assessment of undiscovered petroleum resources of the Amerasia Basin Petroleum Province, *U.S. Geol. Surv. Sci. Invest. Rep. 2012–5146*, 36 p. [Available at http://pub.usgs.gov/sir/2012/5146.]

Houseknecht, D.W., K.J. Bird, and C.P. Garrity (2012b), Assessment of undiscovered petroleum resources of the Arctic Alaska Petroleum Province, *U.S. Geol. Surv. Sci. Invest. Rep. 2012–5147*, 26 p. [Available at http://pubs.usgs.gov/sir/2012/5147.]

Hugelius, G., et al. (2014), Estimated stocks of circumpolar permafrost carbon with quantified uncertainty ranges and identified data gaps, *Biogeosciences*, *11*, 6573–6593, doi:10.5194/bg-11-6573-2014.

Jones, A., et al. (2013), The impact of abrupt suspension of solar radiation management (termination effect) in experiment G2 of the Geoengineering Model Intercomparison Project (GeoMIP), *J. Geophys. Res. Atmos.*, *118*, 9743–9752, doi:10.1002/JGRD.50762.

Kapyla, J., and H. Mikkola (2013), Arctic conflict potential: towards an extra-Arctic perspective, *Finnish Institute of International Affairs Briefing Paper 138*. [Available at http://www.fiia.fi/en/publication/361/arctic_conflict_potential/.]

Kapyla, J. and Mikkola, H. (2015). On Arctic exceptionalism; critical reflections in the light of the Arctic Sunrise case and the crisis in Ukraine, *Finnish Institute of International Affairs Working Paper 85*. [Available at http://www.fiia.fi/en/publication/502/on_arctic_exceptionalism/.]

Kerr, S., J. Colton, K. Johnson, and G. Wright (2015), Rights and ownership in sea country: implications of marine renewable energy for indigenous and local communities, *Mar. Policy*, *52*, 108–115, doi:10.1016/j.marpol.2014.11.002.

Klett, T.R., (2011), Assessment of undiscovered oil and gas resources of the West Siberian Basin Province, Russia, 2010, *U.S. Geological Survey Fact Sheet 2011-3050*, 2 p.

Koenigk, T., U. Mikolajewicz, H. Haak, and J. Jungclaus (2007), Arctic freshwater export in the 20th and 21st centuries, *J. Geophys. Res.*, *112*, G04S41, doi:10.1029/2006JG000274.

Kovacs, K., C. Lydersen, J. Overland, and S. Moore (2011), Impacts of changing sea-ice conditions on Arctic marine mammals, *Mar. Biodivers.*, *41*(1), 181–194, doi:10.1007/s12526-010-0061-0.

Laidre, K. L., et al. (2015), Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century, *Conserv. Biol.*, *29*(3), 724–737, doi:10.1111/cobi.12474.

Lantuit, H., et al. (2012), The Arctic coastal dynamics database: a new classification scheme and statistics on Arctic permafrost coastlines, *Estuar. Coasts*, *35*, 383–400, doi:10.1007/s12237-010-9362-6.

Larsen, J. N. and G. Fondahl (Eds), (2014). The Arctic Human Development Report. *Nordic Council of Ministers*. [Available at http://www.sdwg.org/wp-content/uploads/2015/02/AHDRIIFINALREPORT2015-02-24.pdf, doi: 10.6027/TN2014-567].

Le Quere, C., et al. (2015), Global carbon budget 2015, *Earth Syst. Sci. Data*, *7*, 359–396, doi:10.5194/essd-7-349-2015 [Available at http://www.globalcarbonproject.org/carbonbudget/15/hl-compact.htm.].

Lemelin, R. H., M. E. Johnston, J. Dawson, E. S. Stewart, and C. Mattina (2012), From hunting and fishing to cultural tourism and ecotourism: examining the transitioning tourism industry in Nunavik, *Polar J.*, *2*(1), 39–60, doi:10.1080/2154896X.2012.679559.

MacCracken, J. G. (2012), Pacific Walrus and climate change: observations and predictions, *Ecol. Evol.*, *2*(8), 2072–2090, doi:10.1002/ece3.317.

Mahlstein, I., and R. Knutti (2012), September Arctic sea ice predicted to disappear near 2 °C global warming above present, *J. Geophys. Res.*, *117*, DO6014, doi:10.1029/2011JD016709.

Matthews, H. D., S. Solomon and R. Pierrehumbert (2012). Cumulative carbon as a policy framework for achieving climate stabilization. *Phil. Trans. Royal Soc. A. 370*, 4365–4370, doi: 10.1098/rsta.2012.0064.

Mauritzen, C., and S. Haakkinen (1997), Influence of sea ice on the thermohaline circulation in the Arctic – North Atlantic Ocean, *Geophys. Res. Lett.*, *24*, 3257–3260, doi:10.1029/97GL03192.

Meinshausen, M., N. Meinshausen, W. Hare, S. C. B. Raper, K. Frieler, R. Knutti, D. J. Frame, and M. R. Allen (2009), Greenhouse-gas emission targets for limiting global warming to 2 °C, *Nature*, *458*, 1158–1162, doi:10.1038/nature08017.

Murray, R. (2012), Arctic politics in the emerging multipolar sytem: challenges and consequences, *Polar J.*, *2*(1), 7–20, doi:10.1080/2154896x.2012.679554.

National Research Council (NRC) (2015), Climate intervention: carbon dioxide removal and reliable sequestration, in *Report Prepared by the Committee on Geoengineering Climate: Technical Evaluation and Discussion of Impacts*, Natl. Acad. Sci., Washington, D. C..

Nuttall, M. (2013), Zero-tolerance, uranium and Greenland's mining future, *Polar J.*, *3*(2), 368–383, doi:10.1080/2154896x.2013.868089.

Overpeck, J. T., et al. (2005), Arctic system on trajectory to new, seasonally ice free state, *EOS Trans. Am. Geophys. Union*, *86*(34), 309–316, doi:10.1029/2005EO340001.

Pelletier, S., and F. Lasserre (2012), Arctic shipping: future polar express seaways? Shipowners' opinion, *J. Maritime Law Commerce*, *43*(4), 553–564.

Pizzolato, L., S. Howell, J. Dawson, L. Copland, C. Derksen, and M. Johnston (2013). Climate Change Adaptation Assessment for Transportation in Arctic Waters (CATAW) scoping study, *Summary Rep., A report prepared for Transport Canada*, Ottawa, Canada. [Available at http://www.espg.ca/wp-content/uploads/2013/04/CATAW_Scoping-Study1.pdf.]

Post, E., et al. (2009), Ecological dynamics across the Arctic associated with recent climate change, *Science*, *325*(5946), 1355–1358, doi:10.1126/science.1173113.

Rasmussen, R. O. (2013a), Megatrends in Arctic development, in Proceedings from the First International Conference on Urbanisation in the Arctic Conference 28–30 August, 2012, edited by K. G. Hansen, R. O. Rasmussen, and R. Weber, *Nordregio Working Paper 2013-6*, Nordregio, Stockholm, Sweden, ISBN: 978-91-87295-07-2, pp. 19–24.
Rasmussen, R. O. (2013b), Disporas in the Arctic urbanization, in Proceedings from the First International Conference on Urbanisation in the Arctic Conference 28–30 August, 2012, edited by K. G. Hansen, R. O. Rasmussen, and R. Weber, *Nordregio Working Paper 2013-6*, Nordregio, Stockholm, Sweden, ISBN: 978-91-87295-07-2, pp. 197–211.
Riahi, K., S. Rao, V. Krey, C. Cho, V. Chirkov, G. Fischer, G. Kindermann, N. Nakicenovic, and P. Rafaj (2011), RCP 8.5—A scenario fo comparatively high greenhouse gas emissions, *Clim. Change*, *109*, 33–57, doi:10.1007/s10584-011-0149-y.
Ricke, K. L., M. G. Morgan, and M. R. Allen (2010), Regional climate response to solar-radiation management, *Nat. Geosci.*, *3*, 537–541, doi:10.1038/ngeo915.
Ridley, J. K., J. A. Lowe, and H. T. Hewitt (2012), How reversible is sea ice loss? *Cryosphere*, *6*, 193–198, doi:10.5194/tc-6-193-2012.
Robock, A., L. Oman, and G. L. Stenchikov (2008), Regional climate responses to geoengineering with tropical and Arctic SO_2 injections, *J. Geophys. Res.*, *113*(D16101), 1–15, doi:10.1029/2008JD010050.
Schuur, E. A. G., et al. (2015), Climate change and the permafrost carbon feedback, *Nature*, *520*, 171–179, doi:10.1038/nature14338.
Smith, L. C., and S. R. Stephenson (2015), New Trans-Arctic shipping routes navigable by midcentury, *Proc. Natl. Acad. Sci. U. S. A.*, *110*(13), E1191–E1195, doi:10.1073/pnas.1214212110.
Stirling, I., and A. E. Derocher (2012), Effects of climate warming on polar bears: a review of the evidence, *Global Change Biol.*, *18*(9), 2694–2706, doi:10.1111/j.1365-2486.2012.02753.x.
Stroeve, J. C., V. Kattsov, A. Barrett, M. Serreze, T. Pavlova, M. Holland, and W. Meier (2012), Trends in Arctic sea-ice extent from CMIP5, CMIP3 and observations, *Geophys. Res. Lett.*, *39*, L16502, 1–7, doi:10.1029/2012GL052676.
Struzik, E. (2012), *As Arctic melts Inuit Face Tensions With Outside World. Yale Environment 360*. [Available at http://e360.yale.edu/feature/as_arctic_melts_inuit_face_tensions_with_outside_world/2577/. Downloaded 11/22/2015.]
Tarnocai, C., J. G. Canadell, E. A. G. Schuur, P. Kuhry, G. Mazhitova, and S. Zimov (2009), Soil organic carbon pools in the northern circumpolar permafrost region, *Biogeochem. Cycles*, *23*(2), GB2023, 1–7, doi:10.1029/2008gb003327.
Tedesco, M., et al. (2015), Greenland ice sheet, in *Arctic Report Card: Update for 2015*. [Available at http://www.arctic.noaa.gov/reportcard/greenland_ice_sheet.html.]
Tietsche, S., D. Notz, J. H. Jungclaus, and J. Marotzke (2011), Recovery mechanisms of Arctic summer sea ice, *Geophys. Res. Lett.*, *38*, L02707, doi:10.1029/2010GL045698.
Tilmes, S. J., K. Alexandra, E. Jennifer, M. Holland, and J.-F. Lamarque (2014), Can regional climate engineering save the summer Arctic sea ice? *Geophys. Res. Lett.*, *41*(3), 880–885, doi:10.1002/2013GL058731.
United Nations (1992), *United Nations Framework Convention on Climate Change*. [Available at: http://unfccc.int/key_documents/the_convention/items/2853.php.]
United Nations (2016), *Report of the Conference of the Parties on is Twenty-First Session, Held in Paris From 30 November to 13 December 2015*. [Available at http://unfccc.int/meetings/paris_nov_2015/session/9057.php.]
Vaguet, Yvette (2013), Oil and gas towns in Western Siberia: past, present and future challenges, in Proceedings from the First International Conference on Urbanisation in the Arctic Conference 28–30 August, 2012, edited by K. G. Hansen, R. O. Rasmussen, and R. Weber, *Nordregio Working Paper 2013-6*, Nordregio, Stockholm, Sweden, ISBN: 978-91-87295-07-2, pp. 125–132.
Van Vuuren, D. P., et al. (2011), RCP2.6: exploring the possibility to keep global mean temperature increase below 2 °C, *Clim. Change*, *109*, 95–116, doi:10.1007/s10584-011-0152-3.
Walsh, J. E., and W. L. Chapman (2014), Variability of sea ice over decadal and longer timescales, in *Climate Change: Multidecadal and Beyond*, Vol. 6 of the World Scientific Series of Asia-Pacific Weather and Climate, edited by M. Ghil, M. Latif, J. M. Wallace, and C. P. Chang. World Scientific Publishing Company, Singapore.
Zalkind, Lyudmila (2013), Review of Russian Arctic Regions: urbanization, economy, demography, in Proceedings from the First International Conference on Urbanisation in the Arctic Conference 28–30 August, 2012, edited by K. G. Hansen, R. O. Rasmussen, and R. Weber, *Nordregio Working Paper 2013-6*, Nordregio, Stockholm, Sweden, ISBN: 978-91-87295-07-2, pp. 25–30.
Zheng, H., G. Jia, and H. Epstein (2011), Recent changes in phenology over the northern high latitudes detected from multi-satellite data, *Environ. Res. Lett.*, *6*(2011), 045508 (11pp), doi:10.1088/1748-9326/6/4/045508.
Zysk, Katarzyna (2014). Russia's Arctic Strategy: Ambitions and Constraints. Downloaded from the Norwegian Institute for Defense Studies [Available at http://www.geopoliticsnorth.org/index.php?option=com_content&view=article&id=84&limitstart=2.]